International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 9, Issue 3, Jun 2019, 1379-1392

REVIEW OF VARIOUS TECHNOLOGIES USED FOR BIODIESEL PRODUCTION

C. R. GIRISH

Department of Chemical Engineering, Manipal Institute of Technology,
Manipal Academy of Higher Education, Manipal, Karnataka, India

ABSTRACT

The energy crises, mainly the rapid depletion of fossil fuels are considered as an important global problem. Thus it necessitates to search for an alternative source of fuel to meet the energy demand. Energy can be produced from different sources among which vegetable oils, non-edible oils and organic waste are considered as potential feed stock for producing biodiesel. Biodiesel is an alternative fuel and it solves the problem of depending on the non-renewable resources. But the major concern with the biodiesel production is that it involves high production cost, purification of the final product and technical constraints associated with the process. Therefore in the recent time, lot of improvements are done with respect to biodiesel production process and the attention is paid for developing process intensification technologies to address the above problems. Various modified methods for producing biodiesel are pyrolysis, supercritical process, ultrasound, reactive distillation, reactive separation, microwave technique and membrane separation. Thus in the current study the biodiesel production from these methods were discussed and the benefits and the drawbacks of these processes were reviewed.

KEYWORDS: Biodiesel, Microwave, Ultrasound, Pyrolysis & Transesterification

Received: Apr 17, 2019; **Accepted:** May 07, 2019; **Published:** Jun 03, 2019; **Paper Id.:** IJMPERDJUN2019144

Original Article

INTRODUCTION

Because of rapid growing human population and growing industries there is a demand from society for the energy sources [1]. It is known that energy is absolutely required for the economic growth. The major part of the requirement is met by non-renewable fossil fuels. The fossil fuels are high cost, gets depleted faster with the usage and causes pollution. Even there are strict regulations from the environmental regulatory bodies to reduce the pollution from these fossil fuel sources [2]. Thus there is a growing interest among the researchers to produce energy from an alternative source [3]. The energy requirement can be fulfilled from various sources such as solar, wind, geothermal, hydroelectric source and biosources [2]. The energy production from biosources is served as the effective replacement to fossil fuel.

Biodiesel is produced from various sources such as edible oils, non-edible oils and also from other sources like refineries waste, waste oil and grease oil. The biodiesel is classified as first, second and third generation depending on the material, its properties, the free fatty acids content etc. The first generation biodiesel are mainly obtained from edible oils like corn, rice, sorghum, canola, peanut, jatropha, mahua, karanja, tobacco and sunflower oil [4]. In the developing countries where food security is one of the major concern, instead of edible oils, biodiesel production can be done with other low cost feed stock [5]. The vegetable oil has advantages that is that it can be mixed with petro diesel and used for ignition engines and causes less pollution [2]. It has also benefits that it is

portable, easily available, renewable and has high energy content. But it is highly viscous in nature, costly and less volatile [6]. The second generation biodiesel are produced with the help of non-edible oils and used cooking oils and waste animal fats such as beef tallow, pork lard, fish oil and poultry fat [4]. Non edible oil crops are grown in waste lands and have low cultivation cost and can grow in adverse climatic conditions [7]. The non-edible crops solves the problem of competition for food resources, results in lot of valuable byproducts and considerably economical [8]. These sources have drawback that they have higher acidity and high fatty acids content [9]. The biodiesel produced from sources waste oil from refineries, waste grease oil forms the third generation biodiesel [10]. By depending on these resources, addresses the issue of disposing the waste and improving the environmental impact [4].

The biodiesel produced is safe, renewable, non-toxic, biodegradable in nature, environmentally amicable, has less sulphur content, low emission of SO_2 gas and better lubricant properties [11]. The fuel possesses higher values of flash point, cetane number and can be blended with petrodiesel in different proportions [12]. It concerns about the rural development by creating jobs to the society and causes less pollution [11]. It encourages the entrepreneurs from different countries to invest in the technologies concerned with biodiesel production. The production process complies with the environmental and ethical standards [13]. The biodiesel production minimizes the country's burden to import petroleum from other countries, the biofuel gives better engine performance and has good performance in the competitive market. By using biodiesel decreases the release of particulate matter into the atmosphere and provides a congenial environment to the human health [11]. Thus looking into these aspects, it is required to produce biodiesel from the various low cost feed materials.

Various methods are used for producing biodiesel from available feedstocks. The main reaction path is that triglycerides present in the oil reacts with alcohol to form fatty acid esters of another group i.e. biodiesel and glycerol [14] and is known as transesterification. The reaction is given in the following form as

$$RCOOR' + R''OH \xleftrightarrow{catalyst} RCOOR'' + R'OH$$

Oil Alcohol Ester Glycerol

The biodiesel is produced at the top as lighter layer and the glycerol obtained as the bottom layer, is used for soap preparation [15].

Disadvantages of Conventional Transesterification Process

But the conventional transesterification process has some disadvantages. The biodiesel produced from vegetable oil through transesterification have poor storage stability and cold flow properties [16]. Conventional methods of biodiesel production requires different steps such as oil extraction, purification and transesterification which increases the total cost of the process [17]. The transesterification process requires expensive acidic and basic catalyst to accelerate the rate of biodiesel production [18]. The time required for the process is long and the catalyst consumption is also more [19]. The commercialization of biodiesel from the conventional transesterification is a challenge due to the high cost of vegetable oil used [20]. Therefore the above drawbacks can be overcome by modifying the process and operating conditions to produce biodiesel.

The various modified methods used for producing biodiesel are supercritical process, ultrasound, reactive distillation, reactive separation, pyrolysis, microwave technique and membrane separation. The biodiesel produced from all

the above processes result in product of high purity and better properties. Therefore in the present work the advantages, disadvantages and significant features of the various processes are discussed.

VARIOUS METHODS USED FOR THE BIODIESEL PRODUCTION

Microwave Technology

Microwave is a type of electromagnetic irradiation with wavelength varying from 0.01 to 1 m and frequency in the range of 0.3 to 300 GHz. These are non-ionizing radiations having lower energy content that does not ionize the atoms, but instead affects the molecular motion without changing the structure [21]. It accelerates the chemical reactions and delivers the required energy to the reactants present in the system [22]. The reactants present such as feed oil, alcohol and the catalyst contains polar as well as ionic components and these components absorb the microwave energy [23]. Thus the heat transfer is more efficient when compared to the conventional methods. Because in conventional methods transfer of energy is dependent on convection and thermal conductivity of the system [22,23]. It result in friction between the molecules and heat energy is produced [24]. The process does not require samples free of water [25].

The reaction is carried out in a short period of time [22]. The process requires internal mixing of the components because the microwaves may not reach to the higher depth and uniform mixing may not possible. Thus the system has to be modified and modification in the experimental setup has to be done for reaching the target of biodiesel yield [24]. It has also mass transfer limitations and the localized superheating has to be minimized [26].

Pyrolysis

It is the decomposition of biomass (organic matter) at a higher temperature in the inert atmosphere to produce liquid oil, gas products and bio-char. It is one of the commonly used method for converting the waste materials into useful products [27]. The fuel produced has the properties it can be stored and transported economically. The biodiesel has almost the similar properties when compared with diesel fuel. It can be used for combustion process or can be modified into liquid transport fuels [27].

The pyrolysis process has the following drawbacks. The bio-oil has properties like lower heating value, less volatility, instability that does not satisfy the properties of standard petroleum fuel properties. These are due to the presence of some unwanted chemical compounds. The elimination of oxygen is required to improve the properties of bio-oil and can be done using hydrotreating and catalytic cracking. Hydrotreating employs hydrogen for removing oxygen in the water form, while catalytic cracking uses catalyst to remove oxygen [28]. It is difficult to find out the main product from the pyrolysis because the process is dependent on the experimental conditions such as vapor residence time, temperature of the reaction and the heating rates. The process has main three products liquid oil, solid residue and incondensable gases. Therefore these experimental conditions have to be optimized to obtain the desired product [29].

Supercritical Method

A pure substance has a critical point between the gas and liquid. There is formation of high density fluid (supercritical fluid) above the critical point and cannot be subjected to condensation even after increasing temperature or pressure. In the supercritical state, the various properties such as dissociation constant, dielectric constant, specific gravity, polarity and viscosity changes drastically with respect to temperature and pressure. These properties are beneficial for the reactions involved in biodiesel production [30]. The supercritical technique uses the solvent in the supercritical condition i.e. at the critical temperature and pressure.

The drawbacks found in the catalytic transesterification process like byproducts formed, wastewater generated, high enzyme cost can be eliminated [31]. The separation and purification of the product is simpler and it requires no catalyst [32]. By using the components in supercritical state, homogeneous phase is formed which accelerates the transesterification reaction without using any catalyst. In the homogeneous phase, he gas-liquid interface can be eliminated and the diffusivity of the components can be increased [33]. The reaction happens at relatively higher temperature and pressure. Therefore co-solvent which has critical point lesser than the solvent in the reaction mixture and the co-solvent decreases the critical point of the solution. Thus the reaction can be conducted at a moderate condition and the solubility of the oil and alcohol can be increased [34]. The reaction can be completed faster in shorter because of the operating conditions [31]. Because of the high temperature and pressure maintained in the process, the cost of the process increases and the energy required is more [35]. Safety is one of the important issue with the supercritical method, since the process vessel is operated at higher pressure [18].

Ultrasound Technology

Ultrasound cavitation is advantageous over conventional mixing and forms effective contact between the two immiscible phases. It increases the mass transfer between the feed oil and the reactants during transesterification process. It is considered as cost efficient process compared to the mechanical agitation and provides the activation energy to the transesterification process. The process produces cavitation bubbles which passes through the solution and exerts varying pressure. The bubble collapses suddenly and releases the required amount of energy [19, 36]. The process improves the overall reaction rate, increases the biodiesel yield and decreases the reaction time [37].

The effect of ultrasound depends on two technical factors such as selecting the energy intensity and population of active cavitation. These two parameters are used for finding the efficiency. A large number of experiments are conducted to measure these key factors. Thus some theoretical approach has to be developed to measure these parameters [38]. The process has technical limitations and thus has to be studied thoroughly and research has to be carried out [39].

Reactive Distillation

It is a process in which the chemical reaction and the product separation occur together in the same unit [40]. It is beneficial for the reactions where one of the reactant is present in excess or when one of the product has to be removed for the completion of the reaction [41]. The process does not require any post-processing separation and purification steps. It reduces the number of process units and thus decreasing the cost of the process [42].

Reactive Extraction

The conventional methods for biodiesel production involves various steps such as extracting oil, purification of the oil and the transesterification process. These steps form a major part of the biodiesel production cost. Thus there is a requirement for a method which extracts the oil and also the oil is subjected to transesterification process. In this method oil-containing material is treated with alcohol, so that extraction and transesterification steps are carried out together [17]. Depending on the type of catalyst, the reaction extraction can be chemical or enzymatic type transesterification [43]. Thus the process reduces the number of steps and the cost of the process [44].

Membrane Process

The membrane process involves separating components in a solution by passing through a semi-permeable membrane. The unwanted particles are restrained on the membrane surface [45]. The process uses micro and ultrafiltration membranes made of ceramic and also polymeric membranes. These are used so that the ester conversion is improved [46]. The membrane technique does not require any additive or coagulants, have the ability to work at moderate operating conditions and the undesired products can be avoided [47]. The performance of the membranes depends on the feed conditions, the amount of solvent, temperature, pressure and velocity of flow [45]. The process needs a large initial capital cost [48]. The membrane process results in the fouling because of the accumulation of molecules on the membrane surface [49].

From the available literature, the different techniques used for biodiesel production are studied. The works explains the various advantages and disadvantages of the various processes. It also describes how these processes can solve the problems of the conventional transesterification process. The summarization of all various processes like features, advantages and disadvantages are shown in Table1. The interesting findings from the recent literature like the works done with respect to different methods for biodiesel production, the experimental conditions, the biodiesel yield and potential of the process to handle the feedstock are discussed below.

Table 1: The Summarization of the Technologies Used for Biodiesel Production Showing the Features, Advantages and Disadvantages of the Processes

Features	Advantages	Disadvantages
Microwave: Microwave energy is absorbed by the reactants at the molecular level [50]. The molecules gets heated to the reaction temperature [51].	The method is very effective in attaining the required reaction temperature and uses minimum amount of energy [24]. The preheating step can be avoided because of microwave heating [20, 52]. The heating cost is two thirds lesser compared to conventional process [25]. The reaction rate increases and the solvent vaporizes very fast due to the electromagnetic interaction [24]. An enormous decrease in the formation of by-products is found and the reaction time can be reduced [53]. It increases the rate, product purity and yield [54].	It needs internal mixing because of the limitation that microwaves may not reach to the higher depth. Thus some rearrangement in the experimental setup is required [24]. The technique needs to reduce the localized superheating and has mass transfer limitations [26].
Pyrolysis: It is the thermal decomposition of organic substances at a temperature of 300-1000^{o}C in the inert atmosphere to form liquid, solid and gaseous products [29, 55].	The liquid fuel produced has compatibility in storage, transportation and serves as source of fuel, energy carrier and a chemical [56]. The process is versatile in handling the type of raw material and the conversion occurs faster [57]. The environmental issue of disposing of animal fat waste can be solved by subjecting the animal waste to pyrolysis [55]. By pyrolysis it is possible to convert major part of the biomass into bio-oil which can be further processed [58]. To improve the properties of the biodiesel catalyst can be used in the process. It reduces the temperature and provides the activation energy required for breaking the C–C bonds.	The bio-oils produced have high values of oxygen content, viscosity, acidity and lower heating value which is undesirable fuel property. Therefore, catalytic cracking is required to improve the properties of the produced biodiesel. This is due to the presence of some undesirable compounds [27, 28]. The yield and final properties of the fuel are dependent on the factors such as reactor design and operating conditions [56].

	It lowers the residence time in the reactor and improves the selectivity [59].	
Supercritical method: The solvent is used in the supercritical conditions to improve the properties and the reaction conditions [18].	There is no formation of byproducts, wastewater is not generated, elimination of high cost of enzyme, high product yield and an environmentally friendly process [31]. The reaction can be completed faster, and downstream processing is simpler since there is no catalyst [32]. The feed having water content can be used in the supercritical condition [60]. The components in supercritical state forms homogeneous phase and it accelerates the transesterification reaction without using any catalyst. The gas-liquid interface eliminates in the homogenous phase and the diffusivity of the components in the system improves [33]. A co-solvent with a lower critical point than the solvent can be used to decrease the critical point of the mixture and to increase the solubility in the system [61].	Because of the high temperature and pressure maintained in the process, the cost of the process increases enormously and the energy requirement increases [35]. Safety is one of the important concern with the supercritical process, since the process vessel has to be operated at high severity operating conditions [18].
Ultrasound method: It is an effective technique used for the biodiesel production systems where reaction rate is low. The immiscibility between the reactants results in poor contact between the reactants. With the help of ultrasound the mass transfer between the components can be increased [37].	The surface area required for the reaction increases; It breaks all the components present in the system [62]. The method reduces the reaction time, the contact area between the two immiscible phases increases and mass transfer rate increases. It also reduces the amount of catalyst required [63].	Additional mechanical stirring is required. Horn tip will be eroded easily in probe reactor. It is difficult to control the reaction temperature [38]. Because of technical constraints process requires further study [62]. The process results in the formation of undesired side products [64].
Reactive distillation: It is designed to integrate the reaction and separation steps in a single column thus increasing the mass transfer [65].	It requires minimum capital investment and operating cost. It does not result in any waste streams or soap formation [66]. It increases the conversion and the selectivity in the competing reactions. It eliminates the usage of solvents in the separation step and the formation of azeotrope [65]. The process is advantageous since it eliminates the requirement of external recycle streams from separator units, thus reducing the waste handling [67].	The process requires high energy and the conversion is dependent on efficiency of the catalyst [64].
Reactive extraction: It is in situ transesterification process where the oil-bearing feed stock is mixed with a solvent where extraction and transesterification of the oil takes place [68].	The use of expensive solvent used for oil extraction can be avoided [44]. By removing the pre-extraction process, waste products generated can be reduced and the downstream process can be simplified [69]. It enhances yield and selectivity in the system and recycle streams are reduced [70].	Some of the solvents shows poor properties, thus supercritical solvents has to be used [68]. Because of the reactions formed, it leads to problems such as separating the products and corrosion of the process vessels [43].
Membrane process: The transesterification reaction forms mainly biodiesel (continuous phase) and glycerol (dispersed phase). Therefore purification can be done by two methods. Wet washing with hot water results	The process requires lower operating temperature and pressure. It also improves the properties of the recovered oil [29]. With the help of membrane, the ester conversion increases [46]. The selectivity of the membrane is added advantage which is dependent on the pore size of the membrane [73].	The membranes are expensive and are damaged or fouled by accumulation of larger particles [29]. The operating parameters such as alcohol concentration, catalyst has to be controlled thoroughly in order to prevent the fouling on the

in generation of wastewater. Dry washing with the help of adsorbents requires to regenerate the spent adsorbent. Therefore the process is required for purifying biodiesel and to improve the properties [71, 72].	The process minimizes water consumption during the biodiesel purification process, thus decreasing the overall cost [48]. The membrane provides larger surface area so that two liquid phases are brought closer to each other. The surface area is not disturbed at varying flow rates [74].	membrane. Higher concentration of alcohol makes glycerol and other particles to pass through the membrane and results in fouling [75]. To design, control and optimize the biodiesel production using membrane technique requires the understanding of concepts like convection and diffusion [73].

In the work reported by Khemthong et al., CaO was produced from eggshell waste and used as catalyst for biodiesel production. Palm oil was used as feedstock with methanol as solvent using the microwave technique. The microwave power was varied in the range of 450 to 900 W, solvent to oil ratio in the range of 12:1 to 24:1, microwave irradiation time from 1 to 4 min and catalyst loading 5 to 15 (wt%). The biodiesel yield of 96.7% and microwave technique was effective in increasing the biodiesel conversion [52].

Palm oil was used as feed for the biodiesel production by Ding et al. with the help of microwave. Methanol was used as solvent and three different ionic liquids were used as catalyst. Solvent to oil ratio was varied from 3:1 to 18:1, reaction time was 1h to 8h, acidic imidazolium ionic liquids was varied in the range of 4 to14%, microwave power was 60 W to 210 W. The biodiesel yield was obtained as 98.93% under the optimum conditions [54].

The potential of waste cooking oil as feed for producing biodiesel with the help of microwave technique was investigated by Hong et al. The operating conditions were varied in the range of methanol to oil ratio 2:1 to 14:1, the catalyst 0.2 to 1.4 (wt%), microwave power 200 to 800 W and irradiation time from 2 to 12 min. The biodiesel yield of above 96% was obtained from the above conditions [20].

Martinez-Guerra and Gude explored waste vegetable oil for the biodiesel production using microwave and ultrasound. Methanol to feed was used in the range of 3:1 to 12:1, sodium hydroxide as catalyst in the range of 0.5 to 2.5 (wt%), reaction time varied from 1 to 5 min and microwave power 0 to 200 W for carrying out the reactions. The biodiesel yield of 98% was obtained under these conditions [26].

The applicability of animal fat waste for biofuel production by pyrolysis was investigated by Hassen-Trabelsi et al. The experiments were conducted in a fixed bed reactor heated through an electric furnace. The pyrolysis temperature was varied from 400 to 550^{o}C and heating rate was maintained constant 5^{o}C/ min to 15^{o}C/ min. It was studied that the yields of biofuel obtained varied from 58 to 77.9 wt.%. It was also suggested that biofuel produced needs further enhancement in the properties before it can be used as engine fuel [55].

Castor raw oil was used for producing biodiesel by pyrolysis process in the presence of catalyst. It was found that by using the catalyst by 1% could reduce the pyrolysis temperature and thus saving the energy. Finally it was concluded that the biodiesel obtained was a promising fuel to replace gas oil [56].

Pyrolysis of Nanochloropsis algae using ceria-based catalysts to produced bio-oil was explored by Aysu and Sanna. The pyrolysis temperature was varied from 400 to 600^{o}C. The ceria nanopowder was mixed with alumina, nickel nitrate, zirconia and magnesium nitrate to study the effect of catalyst on the bio-oil yield. It was investigated that the bio-oil conversion of up to 23 (wt%) was obtained under the above experimental conditions [27].

Jatropha oil and Krating oil were taken for producing biodiesel by using supercritical method without using any catalyst. The methanol to oil ratio was varied in the range 20:1 to 60:1, the reaction temperature in the range of 200 to 350^{o}C, the reaction pressure from 8 to 18 MPa and reaction time from 5 to 15 min. The biodiesel yield of 90% was obtained from the experiments [31].

Jiang and Tan investigated the applicability of coconut oil for biodiesel production by supercritical technique in the presence of various co-solvents. The co-solvents were helpful in increasing the solubility between the feed oil and the methanol (solvent). It was possible to obtain biodiesel yield of 72% in the presence of co-solvent which was comparatively higher than 41% without using any co-solvent [35].

The potential of *Pongamiapinnata* oil was tested for biodiesel production by Goembira and Saka. It was studied that at the optimum conditions of 300^{o}C temperature, 20 MPa operating pressure, 45 min of reaction time and 42:1of methyl acetate to oil, the biodiesel yield of 96.6% was obtained [76].

Soybean oil was employed for biodiesel production with methanol as solvent and carbon dioxide as co-solvent. It was found that by increasing the ratio of carbon dioxide the critical temperature of the system decreased. It was also observed that the operating pressure of the system decreases thus making the process safe and economical [61].

The feasibility of different vegetable oils like rapeseed oil, coconut oil, soybean oil, and palm oil for biodiesel production by ultrasound assisted process were investigated by Sáez-Bastante et al. The experimental conditions were varied as potassium hydroxide as catalyst and methanol as solvent. The maximum biodiesel yield was obtained as 79% at the optimum conditions of solvent to oil ratio of 5:1, 0.8% catalyst and 60% amplitude of ultrasound device [63].

Jatropha oil was used for producing biodiesel by ultrasound process using activated carbon supported catalyst. The catalyst tungstophosphoric acid loading was 4% (wt/wt), methanol to oil ratio 20:1 and ultrasonic power of 75%. The biodiesel yield up to 87% was obtained. Thus the experiments proved that feed oil was having the potential to produce biodiesel [37].

The production of biodiesel was explored by using *Oreochromisniloticus* oil using ultrasound assisted process. The experimental parameters were varied as methanol to oil ratio from 1:1 to 11:1, the amount of catalyst sulphuric acid to oil ratio from 0.1 to 2.0 (g/g) and the reaction temperature from 30 to 90^{o}C. The maximum biodiesel yield was obtained as 98.3% [36].

The biodiesel production from waste cooking oil using methanol as solvent and solid heteropolyacid as catalyst was conducted in a reactive distillation unit. The operating conditions were varied as feed flow rate in the range of 115 to 150 mol/h, inlet temperature as 20 to 30^{o}C, methanol to oil ratio as 30:1 to 70:1 and reboiler duty 1 to 1.5 kW. The biodiesel yield of 92.79% was obtained from the experiments. The process was considered to be environmentally friendly because of the reason that methanol can be recycled from the condenser and also the catalyst can be recycled from the product stream [41].

The reactive extraction of Jatrophacurcas L. seeds using methanol as solvent for biodiesel production was investigated by Kasim and Harvey. The operating conditions were varied as seeds particle size of 0.5 -4 mm, reaction temperature 30-60^{o}C, mixing speed of 100- 400 rpm, reaction time 10-60 min, catalyst sodium hydroxide concentration 0.1-0.2 N and solvent to oil ratio of 200:1 to 600:1. It was observed that biodiesel yield of up to 90% was obtained [77].

The reactive extraction of sterilized palm fruit with potassium hydroxide catalyst was investigated. The experiments were carried out under the conditions of reaction time from 8-11 h, ratio of solvent to oil 147:1–225:1, catalyst loading of 1-4%. Biodiesel yield of 97.25% was obtained proving that the palm fruit is a potential feed stock. It was also studied that the yield of biodiesel was 272 and 175 g per kg of raw palm fruit bunch by the reactive extraction and the two-stage extraction followed by transesterification reaction process, respectively [44].

Soybean oil was used to produce biodiesel using ethanol as solvent and sodium hydroxide as catalyst. The solvent to oil ratio was varied from 6:1 to 9:1 and the reaction temperature from 30 to 60^{o}C. The maximum biodiesel yield obtained was 98.7%. The mixture of biodiesel, ethanol and glycerol was passed through a ceramic membrane for the purification process. The transmembrane pressure was varied from 1 to 3 bar to study the glycerol retention. It was noted that glycerol was retained up to 0.014% [46].

Biodiesel was produced from palm oil using methanol as solvent, potassium hydroxide catalyst. The operating conditions were maintained as 1% catalyst, methanol to oil ratio of 6:1, reaction temperature of 60^{o}C and reaction time of 1h. A ceramic membrane made of alumina and titanium dioxde was used for the purifying biodiesel. The transmembrane pressure was varied at 1 to 3 bar and solution flow rate of 60 to 150 L/min was maintained through the membrane. It was possible to have 98.08% of retention coefficient of glycerol [72].

CONCLUSIONS

The present study reviews the various techniques used for the biodiesel production. The processes such a reactive separation, supercritical process, ultrasound, reactive distillation, pyrolysis, microwave technique and membrane separation are capable of handling different types of feedstocks. The membrane technique provides larger surface area so that two liquid phases are brought in contact with each other and separation increases. The microwave process has the advantage that the required reaction temperature is reached faster and the amount of energy needed can be minimized. Pyrolysis is very effective in handling different type of feed and results in efficient energy conversion and improved biodiesel properties. Reactive distillation reduces the number of process units and the overall capital cost of the process. Reactive extraction eliminates the solvent requirement for the transesterification and reduces the operating cost. Supercritical process maintains very high temperature and pressure for the transesterification process and solves the need of using the catalyst. The ultrasound technique increases the surface area required for the reaction and reduces the reaction time. Therefore it can be concluded the problems encountered in the conventional transesterification such as poor properties of the produced biodiesel, purification of the product, expensive cost, lengthy time of the reaction and commercialization of the product can be overcome by employing the above methods.

REFERENCES

1. *I. Shahzadi, S. Sadaf, J. Iqbal, I. Ullah, H.N. Bhatti, 'Evaluation of mustard oil for the synthesis of biodiesel: Pretreatment and optimization study', Environmental Progress & Sustainable Energy, (2017) 1-7.*

2. *E.M. Shahid, Y. Jamal, 'Production of biodiesel: a technical review', Renewable and Sustainable Energy Reviews, 15(9) (2011) 4732-4745.*

3. *B. Aghel,M. Mohadesi,S. Sahraei, M. Shariatifar, 'New heterogeneous process for continuous biodiesel production in microreactors', The Canadian Journal of Chemical Engineering, 95(7) (2017) 1280-1287.*

4. *S. B. Živković,M.V. Veljković,I.B. Banković-Ilić,I.M. Krstić,S.S. Konstantinović,S.B. Ilić,J.M. Avramović,O.S. Stamenković, V.B. Veljković,'Technological, technical, economic, environmental, social, human health risk, toxicological and policy considerations of biodiesel production and use', Renewable and Sustainable Energy Reviews, 79 (2017) 222-247.*

5. *H.A. Choudhury,P. Srivastava, V.S. Moholkar, 'Single-step ultrasonic synthesis of biodiesel from crude Jatrophacurcas oil', AIChE Journal, 60(5) (2014) 1572-1581.*

6. *A. Demirbas,A. Bafail,W. Ahmad, M. Sheikh, 'Biodiesel production from non-edible plant oils', Energy Exploration & Exploitation, 34(2) (2016) 290-318.*

7. *R. Ghanei, 'Improving cold-flow properties of biodiesel through blending with nonedible castor oil methyl ester', Environmental Progress & Sustainable Energy, 34(3) (2015) 897-902.*

8. *A.E. Atabani, A. da Silva César, 'Calophylluminophyllum L.–A prospective non-edible biodiesel feedstock. Study of biodiesel production, properties, fatty acid composition, blending and engine performance', Renewable and Sustainable Energy Reviews, 37 (2014) 644-655.*

9. *J. Milano,H.C. Ong,H.H. Masjuki,A.S. Silitonga,W.H. Chen,F. Kusumo,S. Dharma,A.H. Sebayang, 'Optimization of biodiesel production by microwave irradiation-assisted transesterification for waste cooking oil-Calophylluminophyllum oil via response surface methodology', Energy conversion and management, 158 (2018) 400-415.*

10. *N.M. Daud, S.R.S. Abdullah, H.A. Hasan, S. Yaakob, 'Production of biodiesel and its wastewater treatment technologies: a review', Process Safety and Environmental Protection, 94 (2015) 487-508.*

11. *L.E. Rincón,J.J. Jaramillo, C.A. Cardona, 'Comparison of feedstocks and technologies for biodiesel production: An environmental and techno-economic evaluation', Renewable Energy, 69 (2014) 479-487.*

12. *F. Halek, A. Delavari, A. Kavousi-rahim, 'Production of biodiesel as a renewable energy source from castor oil', Clean Technologies and Environmental Policy, 15(6) (2013) 1063-1068.*

13. *A.A. Kiss, C.S. Bildea, 'A review of biodiesel production by integrated reactive separation technologies', Journal of Chemical Technology & Biotechnology, 87(7) (2012) 861-879.*

14. *V.G. Gude, E. Martinez-Guerra, 'Green chemistry with process intensification for sustainable biodiesel production', Environmental chemistry letters, 16(2) (2018) 327-341.*

15. *K.A. Borges, A.C.F. Batista, H. de Souza Rodrigues, M.H. Terrones, A.T. Vieira, M.F. de Oliveira, 'Production of methyl and ethyl biodiesel fuel from pequi oil (Caryocarbrasiliensis Camb.)', Chemistry and Technology of Fuels and Oils, 48(2) (2012) 83-89.*

16. *Y. Han,F. Stankovikj, M. Garcia-Perez, 'Co-hydrotreatment of tire pyrolysis oil and vegetable oil for the production of transportation fuels', Fuel Processing Technology, 159 (2017) 328-339.*

17. *S.H. Shuit,K.T. Lee,A.H. Kamaruddin, S. Yusup, 'Reactive extraction and in situ esterification of Jatrophacurcas L. seeds for the production of biodiesel, Fuel, 89(2) (2010) 527-530.*

18. *K.T. Tan, K.T. Lee, 'A review on supercritical fluids (SCF) technology in sustainable biodiesel production: Potential and challenges', Renewable and Sustainable Energy Reviews, 15(5) (2011) 2452-2456.*

19. *E. Martinez-Guerra, V.G. Gude, 'Determining optimum pulse mode for ultrasound enhanced biodiesel production', Journal of industrial and engineering chemistry, 35 (2016) 14-19.*

20. *I. K. Hong, H. Jeon,H.Kim, S.B. Lee, 'Preparation of waste cooking oil based biodiesel using microwave irradiation energy', Journal of industrial and engineering chemistry, 42 (2016) 107-112.*

21. I. Manco,L. Giordani,V. Vaccari, M. Oddone, 'Microwave technology for the biodiesel production: Analytical assessments, Fuel, 95 (2012) 108-112.
22. F. Motasemi, F.N. Ani, 'A review on microwave-assisted production of biodiesel', Renewable and Sustainable Energy Reviews, 16(7) (2012) 4719-4733.
23. J.J. Lin, Y.W. Chen, 'Production of biodiesel by transesterification of Jatropha oil with microwave heating', Journal of the Taiwan Institute of Chemical Engineers, 75 (2017) 43-50.
24. D. Priyadarshi, K.K. Paul, 'Single phase blend: An advanced microwave process for improved quality low-cost biodiesel production from kitchen food waste', Biochemical engineering journal, 137 (2018) 273-283.
25. S. Wahidin, A. Idris, S.R.M. Shaleh, 'Rapid biodiesel production using wet microalgae via microwave irradiation', Energy conversion and management, 84 (2014) 227-233.
26. E. Martinez-Guerra, V.G. Gude, 'Synergistic effect of simultaneous microwave and ultrasound irradiations on transesterification of waste vegetable oil', Fuel, 137 (2014) 100-108.
27. T. Aysu, A. Sanna, 'Nannochloropsis algae pyrolysis with ceria-based catalysts for production of high-quality bio-oils', Bioresource technology, 194 (2015) 108-116.
28. R. French, S. Czernik, 'Catalytic pyrolysis of biomass for biofuels production', Fuel Processing Technology, 91(1) (2010) 25-32.
29. S.S. Lam,R.K. Liew,A. Jusoh,C. T. Chong,F.N. Ani, H.A. Chase, 'Progress in waste oil to sustainable energy, with emphasis on pyrolysis techniques', Renewable and Sustainable Energy Reviews, 53 (2016) 741-753.
30. J.S. Lee, S. Saka, 'Biodiesel production by heterogeneous catalysts and supercritical technologies', Bioresource technology, 101(19) (2010) 7191-7200.
31. A. Samniang,C. Tipachan, S. Kajorncheappun-Ngam, 'Comparison of biodiesel production from crude Jatropha oil and Krating oil by supercritical methanol transesterification', Renewable energy, 68 (2014) 351-355.
32. G.T. Ang,K.T. Tan, K.T. Lee, 'Recent development and economic analysis of glycerol-free processes via supercritical fluid transesterification for biodiesel production', Renewable and Sustainable Energy Reviews, 31 (2014) 61-70.
33. V.F. Marulanda, 2012. 'Biodiesel production by supercritical methanol transesterification: process simulation and potential environmental impact assessment', Journal of Cleaner Production, 33 (2012) 109-116.
34. M. Tobar, G.A. Núñez, 'Supercritical transesterification of microalgae triglycerides for biodiesel production: Effect of alcohol type and co-solvent', The Journal of Supercritical Fluids, 137 (2018) 50-56.
35. J.J. Jiang, C.S. Tan, 'Biodiesel production from coconut oil in supercritical methanol in the presence of cosolvent', Journal of the Taiwan Institute of Chemical Engineers, 43(1)(2012) 102-107.
36. F.F. Santos,J.Q. Malveira,M.G. Cruz, F.A. Fernandes, 'Production of biodiesel by ultrasound assisted esterification of Oreochromisniloticus oil', Fuel, 89(2) (2010) 275-279.
37. A.S. Badday,A.Z. Abdullah, K.T. Lee, 'Transesterification of crude Jatropha oil by activated carbon-supported heteropolyacid catalyst in an ultrasound-assisted reactor system', Renewable Energy, 62 (2014) 10-17.
38. J. Luo,Z. Fang, R.L. Smith Jr, 'Ultrasound-enhanced conversion of biomass to biofuels', Progress in Energy and Combustion Science, 41 (2014) 56-93.

39. *V.B. Veljković, J.M. Avramović, O.S. Stamenković, 'Biodiesel production by ultrasound-assisted transesterification: State of the art and the perspectives', Renewable and Sustainable Energy Reviews, 16(2) (2012) 1193-1209.*

40. *N.N. Boon-anuwat,W. Kiatkittipong, F. Aiouache, S. Assabumrungrat, 'Process design of continuous biodiesel production by reactive distillation: Comparison between homogeneous and heterogeneous catalysts', Chemical Engineering and Processing: Process Intensification, 92 (2015) 33-44.*

41. *I. Noshadi,N.A.S. Amin, R.S. Parnas, 'Continuous production of biodiesel from waste cooking oil in a reactive distillation column catalyzed by solid heteropolyacid: optimization using response surface methodology (RSM)', Fuel, 94 (2012) 156-164.*

42. *T. Poddar, A. Jagannath, A. Almansoori, 'Use of reactive distillation in biodiesel production: A simulation-based comparison of energy requirements and profitability indicators', Applied energy, 185 (2017) 985-997.*

43. *Y. Jiang,D. Li, Y. Li,J. Gao, L. Zhou, Y. He, 'In situ self-catalyzed reactive extraction of germinated oilseed with short-chained dialkyl carbonates for biodiesel production' ,Bioresource technology, 150 (2013) 50-54.*

44. *P. Jairurob, C. Phalakornkule, A. Na-udom, A. Petiraksakul, 'Reactive extraction of after-stripping sterilized palm fruit to biodiesel', Fuel, 107 (2013) 282-289.*

45. *I.M. Atadashi, 'Purification of crude biodiesel using dry washing and membrane technologies', Alexandria Engineering Journal, 54(4) (2015) 1265-1272.*

46. *M.C.S. Gomes,P.A. Arroyo, N.C. Pereira, 'Biodiesel production from degummed soybean oil and glycerol removal using ceramic membrane', Journal of membrane science, 378(1-2) (2011) 453-461.*

47. *F. Giorno,R. Mazzei, L. Giorno, 'Purification of triacylglycerols for biodiesel production from Nannochloropsis microalgae by membrane technology', Bioresource technology, 140 (2013) 172-178.*

48. *J.J. Torres, N.E. Rodriguez, J.T. Arana, N.A. Ochoa, J. Marchese, C. Pagliero, 'Ultrafiltration polymeric membranes for the purification of biodiesel from ethanol', Journal of cleaner production, 141 (2017) 641-647.*

49. *K. Prochaska, J. Antczak, M. Regel-Rosocka, M. Szczygiełda, 'Removal of succinic acid from fermentation broth by multistage process (membrane separation and reactive extraction)', Separation and Purification Technology, 192 (2018) 360-368.*

50. *Y. Ning, S. Niu, 'Preparation and catalytic performance in esterification of a bamboo-based heterogeneous acid catalyst with microwave assistance. Energy Conversion and Management', 153 (2017) 446-454.*

51. *S. Yousefi, M. Haghighi, B.R. Vahid, 'Facile and efficient microwave combustion fabrication of Mg-spinel as support for MgO nanocatalyst used in biodiesel production from sunflower oil: Fuel type approach', Chemical Engineering Research and Design, 138 (2018) 506-518.*

52. *P. Khemthong, C. Luadthong, W. Nualpaeng, P. Changsuwan, P. Tongprem, N. Viriya-Empikul, K. Faungnawakij, 'Industrial eggshell wastes as the heterogeneous catalysts for microwave-assisted biodiesel production', Catalysis Today, 190(1) (2012) 112-116.*

53. *M.C. Hsiao,C.C. Lin, Y.H. Chang, 'Microwave irradiation-assisted transesterification of soybean oil to biodiesel catalyzed by nanopowder calcium oxide', Fuel, 90(5)(2011) 1963-1967.*

54. *H. Ding, W. Ye,Y. Wang, X. Wang, L. Li, D. Liu, J. Gui,C. Song, N. Ji, 'Process intensification of transesterification for biodiesel production from palm oil: Microwave irradiation on transesterification reaction catalyzed by acidic imidazolium ionic liquids', Energy, 144 (2018) 957-967.*

55. *A.B. Hassen-Trabelsi, T. Kraiem, S. Naoui, H. Belayouni, 'Pyrolysis of waste animal fats in a fixed-bed reactor: Production and characterization of bio-oil and bio-char', Waste management, 34(1) (2014)210-218.*

56. *M.S.H. Abdelfattah, O.S.M. Abu-Elyazeed, M.A. Abdelazeem, 'On biodiesels from castor raw oil using catalytic pyrolysis', Energy, 143 (2018) 950-960.*

57. *A.B.H. Trabelsi, K. Zaafouri, W. Baghdadi, S. Naoui, A. Ouerghi, 'Second generation biofuels production from waste cooking oil via pyrolysis process', Renewable energy, 126 (2018) 888-896.*

58. *M. Garcia-Perez, J. Shen, X.S. Wang, C.Z. Li, 'Production and fuel properties of fast pyrolysis oil/bio-diesel blends', Fuel Processing Technology, 91(3) (2010) 296-305.*

59. *C. Kassargy, S. Awad, G. Burnens, K. Kahine, M. Tazerout, 'Gasoline and diesel-like fuel production by continuous catalytic pyrolysis of waste polyethylene and polypropylene mixtures over USY zeolite', Fuel, 224 (2018) 764-773.*

60. *N.F. Nasir, W.R.W. Daud, S.K. Kamarudin, Z. Yaakob, 'Process system engineering in biodiesel production: A review', Renewable and Sustainable Energy Reviews, 22 (2013) 631-639.*

61. *H. Han, W. Cao, J. Zhang, 'Preparation of biodiesel from soybean oil using supercritical methanol and CO2 as co-solvent', Process Biochemistry, 40(9) (2005) 3148-3151.*

62. *M. Karimi, B. Jenkins, P. Stroeve, 'Ultrasound irradiation in the production of ethanol from biomass', Renewable and Sustainable Energy Reviews, 40 (2014) 400-421.*

63. *J. Sáez-Bastante, S. Pinzi, G. Arzamendi, M.L. De Castro, F. Priego-Capote, M.P. Dorado, 'Influence of vegetable oil fatty acid composition on ultrasound-assisted synthesis of biodiesel', Fuel, 125 (2014) 183-191.*

64. *I. Ambat, V. Srivastava, M. Sillanpää, 'Recent advancement in biodiesel production methodologies using various feedstock: A review', Renewable and Sustainable Energy Reviews, 90 (2018) 356-369.*

65. *Y.S. Pradana,A. Hidayat, A. Prasetya, A. Budiman, 'Biodiesel production in a reactive distillation column catalyzed by heterogeneous potassium catalyst', Energy Procedia, 143 (2017) 742-747.*

66. *C.S. Bildea, A.A. Kiss, 'Dynamics and control of a biodiesel process by reactive absorption', Chemical engineering research and design, 89(2) (2011) 187-196.*

67. *N.M. Eleftheriades, H. von Blottnitz, 'Thermodynamic and kinetic considerations for biodiesel production by reactive distillation', Environmental Progress & Sustainable Energy, 32(2) (2013) 373-376.*

68. *S. Lim, K.T. Lee, 'Investigation of impurity tolerance and thermal stability for biodiesel production from Jatrophacurcas L. seeds using supercritical reactive extraction', Energy, 68 (2014) 71-79.*

69. *S. Lim, K.T. Lee, 'Process intensification for biodiesel production from Jatrophacurcas L. seeds: supercritical reactive extraction process parameters study', Applied energy, 103 (2013) 712-720.*

70. *K.J. Dussan, C.A. Cardona, O.H. Giraldo, L.F. Gutiérrez, V.H. Pérez, 'Analysis of a reactive extraction process for biodiesel production using a lipase immobilized on magnetic nanostructures', Bioresource technology, 101(24) (2010) 9542-9549.*

71. *M.M.A. Shirazi, A.Kargari, S. Bazgir, M. Tabatabaei, M.J.A. Shirazi, M.S. Abdullah,T. Matsuura, A.F. Ismail, 'Characterization of electrospun polystyrene membrane for treatment of biodiesel's water-washing effluent using atomic force microscopy', Desalination, 329 (2013) 1-8.*

72. *I.M. Atadashi, M.K. Aroua, A.A. Aziz, N.M.N. Sulaiman, 'Crude biodiesel refining using membrane ultra-filtration process: An environmentally benign process', Egyptian Journal of Petroleum, 24(4) (2015) 383-396.*

73. *B. Sajjadi,A.A. Aziz,S. Baroutian, S. Ibrahim, 'Investigation of convection and diffusion during biodiesel production in packed membrane reactor using 3D simulation', Journal of Industrial and Engineering Chemistry, 20(4) (2014) 1493-1504.*

74. *A. Amelio, L. Loise, R. Azhandeh, S. Darvishmanesh, V. Calabró, J. Degrève, P. Luis, B. Van der Bruggen, 'Purification of biodiesel using a membrane contactor: Liquid–liquid extraction', Fuel processing technology, 142 (2016) 352-360.*
75. *S.H. Shuit, Y.T. Ong, K.T. Lee, B. Subhash, S.H. Tan, 'Membrane technology as a promising alternative in biodiesel production: a review', Biotechnology Advances, 30(6) (2012) 1364-1380.*
76. *F. Goembira, S. Saka, 'Advanced supercritical Methyl acetate method for biodiesel production from Pongamiapinnata oil', Renewable energy, 83 (2015) 1245-1249.*
77. *F.H. Kasim, A.P. Harvey, 'Influence of various parameters on reactive extraction of Jatrophacurcas L. for biodiesel production', Chemical Engineering Journal, 171(3) (2011) 1373-1378.*
78. *D. A. Sampatrao, M. G. Sunil, & P. D. Kulkarni (2014). Performance & Emission Analysis of Biodiesel Using Various Blends (Castor Oil+ Neem Oil Biodiesel). Impact Journal, 2, 117-123.*